FUNDAMENTALS OF CARRIER TELEPHONE

CONTENTS

1. GENERAL

1.01 This section is intended to provide REA borrowers, consulting engineers, and other interested parties with technical information on the fundamentals of carrier equipment for subscriber and trunk applications. It is not intended to provide a complete description of carrier theory since this would be beyond the scope of this Manual. Detailed application information for carrier systems will be found in other sections of the Manual.

1.02 The term "Carrier System" is used herein to describe equipment which provides additional talking and signaling paths over wire circuits without interfering with the normal use of these circuits.

For telephonic applications a carrier system can generally be classified as either a trunk or a subscriber type, depending upon the terminations employed at the terminals of the system.

1.03 Various types of trunk carrier systems are used to provide additional telephone trunks between central offices by superimposing them on any of the following types of facilities:

(a) Open wire lines together with entrance cable at each end of the circuit. In addition, intermediate cables may also be present in certain arrangements.

(b) Cable pairs interconnecting the central offices.

(c) Slightly modified carrier systems on electric transmission or distribution lines over a portion of the route together with open wire or cable pairs, or combinations of these latter two facilities, at the central office ends of these circuits.

(d) Slightly modified trunk carrier systems to provide frequency division multiplexing* of radio equipment in order to provide trunk circuits by means of point-to-point radio systems.
(See REA-TE & CM-930)

1.04 Various types of subscriber carrier systems can be used to provide additional telephone subscriber circuits between a central office and remotely located subscribers or groups of subscribers by superimposing them on any of the following types of facilities:

(a) Open wire lines with entrance cable or multi-pair distribution wire at one end of the circuit.

(b) Multi-pair distribution wire or cable pairs.

(c) Slightly modified carrier systems on electric distribution lines over the major portion of the route together with open wire or cable pairs, or combinations of these latter two facilities, at the central office end of these circuits.

(d) Slightly modified subscriber carrier systems to provide frequency division multiplexing of radio equipment in order to provide subscriber circuits by means of point-to-point radio systems.
(See REA-TE & CM-930)

1.05 A basic carrier system for supplying one additi-
or subscriber line usually consists of
by a wire pair or a radio system. Eac
contains a low power transmitter and a
frequencies differ sufficiently so as
operation of each without interference
and signaling equipment to permit prop
tion with the opposite carrier termina
ing and signaling equipment distinguis
system from a trunk carrier system. A
can be further subdivided into several

*A method of transmitting and receiving two or m
on the same radio frequency carrier wave.

vacuum tube or metallic rectifiers for power supplies, vacuum tube or transistor amplifiers and oscillators, vacuum tube, transistor or varistor modulators and demodulators, hybrid circuits, relays and signaling arrangements. Before considering how a carrier channel functions a brief explanation of the various components mentioned above will be given.

1. WAVE FILTERS[1]

2.01 One of the most important groups of components for any carrier system are wave filters. These devices make it possible to utilize various carrier frequencies simultaneously without interference and together with amplifiers, they make carrier techniques practicable for telephone applications. A wave filter is defined as a selective network designed to have a negligible transmission loss to currents over a certain definite range or ranges of frequencies while having an appreciable loss at all other frequencies. Wave filters consist of various combinations of inductors and capacitors or resistors and capacitors inserted in circuits to derive the desired results. The more commonly used types of wave filters can be classified as follows:

2.011 Low Pass - A low pass filter is a structure which readily passes currents of all frequencies from zero up to a certain frequency (called the cut-off frequency) and which effectually bars currents of all higher frequencies.

2.012 High Pass - A high pass filter is one which passes currents of all frequencies from infinity down to a certain frequency (also called the cut-off frequency), and effectually bars currents of all lower frequencies.

2.013 Band Pass - A band pass filter is one which readily passes currents that lie between two cut-off frequencies and effectually bars currents of all frequencies outside of this range.

2.014 Band Elimination - A band elimination filter is a structure which effectually bars currents that lie between two cut-off frequencies and readily passes currents of all frequencies outside of this range.

2.02 The first three types of filters defined above are usually employed in most carrier systems as will be explained later, while the fourth type of filter is used in carrier systems employing certain types of signaling arrangements and in special line treatment applications. Manufacturers sometimes

---

1. "Transmission Circuits for Telephonic Communication" by K. S. Johnson, D. Van Nostrand Co., Inc., 1924, Chapter XVI, Page 180.

apply other names to the fundamental types of wave filters described above or to combinations of these fundamental types. Some of these names are line filters, directional filters, roof filters, separation filters, waystation filters, bridged station filters, voice pass filters, carrier pass filters, transfer filters, and coupling networks. Some of these filters will be further described in subsequent paragraphs or in other sections of the Manual.

2.03 A combination of a low pass and a high pass filter, mounted in the same enclosure, is commonly referred to as a line filter. Various forms of line filters are widely used in carrier system applications. Some of their more common applications are listed below:

2.031 For separating currents at voice frequencies from currents at carrier frequencies.

2.032 For separating two groups of carrier frequency currents in situations where several different types of carrier systems utilize the same wire pair.

2.033 For confining carrier currents to only the desired direction of transmission in some situations where carrier systems are bridged onto the same wire pair at various locations along a route. This application prevents additional attenuation of carrier frequencies due to bridged open circuited taps, resonance effects, etc.

2.034 For providing various bypassing arrangements to transfer carrier currents from one voice frequency wire pair to another.

2.035 For bypassing carrier currents around intermediate voice frequency repeaters.

2.036 For bypassing voice frequency currents around carrier frequency repeaters.

2.04 Line filters are designed for mounting at carrier terminals at central offices or at other locations along a carrier route, such as at cable-open wire junctions, taps, etc. Where mounted external to the central office they are usually supplied in weatherproof housings together with the necessary electrical protective arrangements, impedance matching and balancing devices.

2.05 As an example of the application of line filters to separate currents at voice frequencies from currents at carrier frequencies (Par. 2.031) consider a situation where a three channel trunk carrier system, whose operating frequencies extend from 3.5 KC to 35 KC, is superimposed upon a physical

trunk circuit. In this situation line filters would be added to this circuit as shown in Fig. 1. The low pass filter portion of the line filter would probably have a cut-off frequency in the vicinity of 3.2 KC, depending upon the particular filters utilized.

2.051 Currents of any frequency above this cutoff frequency resulting from the use of any telephone instruments or other apparatus present on the physical trunk circuit at either central office are prevented from causing possible interference to the operation of the carrier system by being attenuated sufficiently before reaching the wire pair used for transmitting both voice and carrier currents between the central offices.

2.052 The low pass filters also prevent any currents at carrier frequencies which are on the wire pair between the filters from reaching the physical trunk circuits at the central offices so as to prevent increased attenuation of the carrier currents by equipment bridged across the physical trunk circuit or other circuits to which it is switched as well as preventing possible interfering effects to voice frequency transmission on the physical circuit due to undesired demodulation of carrier currents by varistors, etc. which may be present in the central offices, telephone instruments, etc.

2.053 The high pass filters will pass currents of all frequencies above 3.2 KC. Therefore, currents at the carrier frequencies (3.5 KC to 35 KC) can be transmitted between the central offices by means of the same wire pair used for voice currents.

2.054 The high pass filters also prevent currents on this wire pair at frequencies below approximately 3.2 KC, from reaching the carrier apparatus at levels which could interfere with its normal operation.

2.06 From this example, it can be seen how a single pair of wires can be utilized for both voice and carrier operation without mutual interference. Similarly, line filters as used in the other applications mentioned in Par. 2.03 effectively isolate higher frequency carrier currents from lower frequency carrier currents and voice currents. The function of these line filters is similar to that described above but the cutoff frequencies can be changed for the particular application. Other examples of wave filter usage will be given in subsequent paragraphs.

3. RECTIFIERS

3.01 Rectifiers are electronic devices for converting alternating

currents to direct currents. A rectifier circuit consists of one or more vacuum or gas filled diode tubes (two element) or metallic or semi-conductor types of diodes together with the necessary inductors, capacitors, transformers, etc. for providing a filtered direct current at the desired voltage. Rectifier circuits are used in A.C. powered carrier equipment for providing the proper D.C. voltages and currents for application to the various elements of vacuum tube or transistor circuits.

3.02 Rectifiers (diodes) are also used in carrier equipment for modulation, demodulation, amplitude limiting, and in various signaling transmitting and receiving arrangements. These functions will be further explained in subsequent paragraphs.

4. AMPLIFIERS

4.01 Amplifiers are electronic devices for providing an increase in the strength of carrier or voice frequency currents in order to overcome unavoidable transmission losses incurred in wire lines, filters, networks and other equipment used in telephone plant. An amplifier stage usually consists of an amplifying type of vacuum tube or transistor together with associated resistors, inductors, capacitors, transformers and power supply. In some instances, several stages of amplification may be necessary for either carrier or voice frequency currents in order to obtain the desired output power. Modern amplifiers can be designed to provide almost any degree of gain required but, in general, amplifiers are usually designed to provide only sufficient gain over the required frequency range for the type of equipment in which they are used. The various types of amplifiers used in carrier systems must not introduce excessive noise or distortion[2] to carrier or voice frequency currents.

5. OSCILLATORS

5.01 Oscillators as used in carrier systems refer to various types of electronic devices utilizing the amplifying ability of vacuum tubes or transistors in such a way that sustained alternating currents are generated at either voice or carrier frequencies. The frequency at which an oscillator operates is usually determined by the proper combination of circuit components used in conjunction with the amplifying device. Frequency determining components are usually either combinations of inductors and capacitors or resistors and capacitors, or quartz crystals of various thicknesses. In addition to the amplifying device and frequency determining components an oscillator is also composed of additional resistors, capacitors, inductors and a power supply.

---

2. The production of an output waveform which is not a true reproduction of the input waveform.

5.02 Oscillators are used in the modulation process of carrier systems (Par. 6) for translating voice frequency currents into a desired position in the carrier frequency spectrum for transmission over a circuit at carrier frequencies. They also provide a means for transmitting dial pulse, ringing information, pilot channel levels and other signaling functions necessary for proper carrier system operation.

6. MODULATION

6.01 Modulation is a process which employs electronic devices such as vacuum tube, transistor, or varistor arrangements for mixing the carrier frequency currents (generated by the oscillator) and voice frequency currents in order to transmit intelligence at carrier frequencies.

6.02 Amplitude modulation is a complex phenomena in which the mixing of currents at voice and carrier frequencies to vary the carrier current amplitude results in the generation of currents of various other frequencies and bands of frequencie The sum and difference of the carrier frequency and the band of voice frequencies which modulated it are particularly important and are called the upper and lower sidebands, respectively.

6.03 The amplitude modulation principle applies generally to carrier systems employing either double sideband carrier transmitted, single sideband carrier transmitted, and single sideband carrier suppressed modulating techniques.

6.04 As an example of sideband generation in an amplitude modulate carrier system consider the situation where a 10 kilocycle carrier frequency current is modulated by a band of voice frequency currents ranging from 250 to 2800 cycles per second Currents of these frequencies are mixed in the modulator circuit. The output of the modulator will contain currents in a lower sideband (carrier frequency minus voice frequency band) extending from 7.2 KC to 9.75 KC and currents in an upper sideband (carrier frequency plus voice frequency band) extending from 10.25 KC to 12.8 KC. Either of these sidebanc contain the desired intelligence for transmittal over the circuit at carrier frequencies. The carrier frequency of 10 KC may or may not appear in the demodulator output, dependin upon the type of modulator circuitry utilized.

6.041 Carrier systems employing a double sideband transmitt carrier modulating technique would, for the example given above, transmit currents of the lower sideband (7.2 KC to 9.75 KC), the carrier frequency (10 KC) and the upper sideband (10.25 KC to 12.8 KC).

6.042 Carrier systems employing a single sideband transmitted carrier modulating technique would, for the example given in Par. 6.04, transmit currents at either the lower or upper sideband plus the carrier frequency. The wanted sideband and the carrier frequency would be transmitted through the proper type of bandpass filter (Par. 2.013) with little attenuation, while the unwanted sideband would be rejected by this same filter.

6.043 Carrier systems employing a single sideband suppressed carrier modulating technique would, for the example given in Par. 6.04, transmit currents of either the lower or the upper sideband only. The modulator circuitry would probably be of a type in which the carrier frequency itself would be suppressed while the wanted sideband would be transmitted by means of the proper type of bandpass filter. The unwanted sideband would be rejected by this same filter.

6.05 It can be seen from the above paragraphs that the amount of frequency spectrum occupied by an amplitude modulated carrier system depends upon the modulating technique adapted and the filter characteristics.

6.06 A simplified diagram of a vacuum tube type modulator sometimes used in carrier systems in shown in Fig. 2. In this type of circuit carrier frequency voltage derived from an oscillator is applied in series with the normal negative bias voltage for the vacuum tubes. This carrier frequency voltage is applied in the same phase to both vacuum tube grids. The resultant carrier frequency currents in the plate circuits of the tubes are in such directions that no carrier frequency current is available at the secondary of output transf
(T2.) In this manner the carrier frequency can be
The voice frequency voltages are, however,
in a manner similar to that of an ord
stage where the grids are out of ph
modulation, the output of T2 will c
and upper sidebands, the voice frequency band and a certain small amount of other unwanted frequency components resulting from modulation. A bandpass wave filter is usually connected between the output of T2 and the carrier line. This filter selects currents of the desired sideband to be transmitted and suppresses all other unwanted modulation products.

6.07 Copper oxide, germanium, and various silicon junction alloys are receiving increased use for modulators in lieu of vacuum tube types in modern carrier equipment designs employing

amplitude modulation techniques.[1] A simplified s
a modulator circuit which could use any of the ty
components mentioned above is shown in Fig. 3. T
are connected to act effectively like a switch, o
closing at a rate equal to the frequency of the c
The action of the circuit is such that the carrie
frequency currents mix to form a lower and an upp
but the carrier frequency current is again suppre
the output due to the circuitry employed. This t
figuration is only one of several types that can
for producing amplitude modulation without vacuum

6.08 In a frequency or phase modulated carrier system
carrier frequency currents or the phase of the ca
quency currents is made to vary at a rate which i
of the voice or signaling currents to be transmit
addition, the carrier frequency deviates during m
within fixed limits above and below its center fr
(no modulation). The amplitude of the carrier fr
not made to vary in order to transmit intelligence
this form of modulation technique.

6.081 Frequency and phase modulation systems are
different. The terms "frequency modulatio
modulation" merely denote which parameter i
accordance with the modulating wave (voice
be transmitted), since any variation of the
a sinusoidal carrier frequency is accompani
frequency variation while any frequency cha
involves a phase change.[2]

6.082 Frequency and phase modulation are both use
systems, although the carrier systems are c
referred to as frequency modulated types de
differences in modulator circuitry. Phase
carrier systems usually have their oscillat
quencies crystal controlled, while frequenc
systems usually employ reactance tube modul
with suitable frequency stabilization techn

6.09 Both frequency and phase modulation are a complex
which create a large number of sidebands in additi
carrier frequency as compared with only the upper
sidebands of amplitude modulated carrier systems.
magnitude of the carrier frequency and sidebands d

---

1. Varistor Modulators for Carrier Systems, by R. S. Caruth
Electric Co. AIEE Paper No. 54-218.
2. Modulation Theory - By H. S. Black, D. Van Nostrand Co.,
3. Principles of Electricity Applied to Telephone and Teleg
1953 Edition, Pg. 262, AT&T Co.

the amount of frequency or phase deviation for the part modulating frequencies used. Although many sidebands a created by these modulating processes it is practical t transmit only those pairs which contain most of the tot energy and still maintain low distortion. This approac considerably reduces the bandwidth needed for transmitt and receiving frequency or phase modulated carriers, bu somewhat greater bandwidth is still needed as compared that required with amplitude modulated carriers. Althou requiring greater bandwidth, some types of frequency or modulated carrier systems have advantages over some type amplitude modulated carrier systems from the standpoint minimizing interference resulting from particular types noise and other extraneous signals.

7. DEMODULATION

7.01 Demodulation is a process which employs electronic devic such as vacuum tubes, transistors, or varistors in arran ments for separating the desired voice frequency intelli from the received modulated carrier sideband or sideband

7.02 Demodulator circuits for single sideband suppressed carr systems are very similar to the modulator circuits as sh in Figures 2 and 3. In these circuits carrier frequency current obtained from a local oscillator (which is the s as the oscillator frequency at the transmitted end of th carrier system) is mixed with the incoming sideband. Th mixing of frequencies in this circuit again results in t generation of an upper and a lower sideband while the os frequency is suppressed in the output due to the balance transformer windings.

7.03 As an example of demodulation in a single sideband suppr carrier system consider the situation where currents at lower sideband of a 10 KC carrier (Par. 6.04) extending f 7.2 KC to 9.75 KC are transmitted to the opposite termin and accepted by the carrier receiver. After amplificati at carrier frequencies this sideband is applied to a dem circuit where it is mixed with a locally generated oscil frequency of 10 KC. Among the various products of demodu will be currents of a lower sideband (carrier frequency m received sideband frequency) extending from 250 to 2800 c and an upper sideband (carrier frequency plus received si extending from 20.25 KC to 22.8 KC. The carrier frequenc the unwanted sideband (20.25 KC to 22.8 KC) and other unw modulation products are removed from the desired voice fr quencies by means of wave filters, balanced transformer windings, etc. The resulting voice frequency (lower side should have relatively little distortion after going thro the processes of modulation at the transmitter, transmitt the line and demodulation at the receiver.

7.04 Demodulator circuits for both single sideband transmitted carrier systems and double sideband transmitted carrier systems perform in essentially the same manner to recover the audio frequency intelligence. The major difference in the demodulator circuitry for these systems as compared with suppressed carrier systems is the fact that a locally generated oscillator frequency corresponding to the oscillator at the modulator terminal is not necessary since the carrier frequency itself is transmitted together with the sideband information.

7.05 Demodulators for frequency or phase modulated carrier systems differ considerably from those used in amplitude modulated systems. In a frequency or phase modulated receiver the desired carrier and its sidebands are selected by a bandpass filter and amplified in the normal manner. They are then passed through a limiter circuit, which is an amplifier designed to produce only a small amount of amplitude gain. After a carrier and sideband input level is reached where carrier frequency amplifier gain no longer occurs any increase in the amplitude of the received carrier frequency or its sidebands does not result in any increase in amplitude at the limiter output.

With such an arrangement the amplitude of the received carrier and its sidebands can vary appreciably but, if the received signal is still strong enough to cause limiting action, the carrier system beyond this stage is insensitive to any amplitude variations caused by modulation, noise, line attenuation variations, etc. The limiter stage thus removes all amplitude variations from received intelligence prior to demodulation. Following the limiter stage only the resulting frequency or phase variations of the carrier frequency and its sidebands are applied to a discriminator circuit. The discriminator circuit is frequency sensitive and produces audio frequency voltages in accordance with the frequency or phase deviations imparted to the carrier frequency at the modulator stage. The discriminator circuit consists of either vacuum tube or varistor networks together with associated components.

7.06 There is another type of demodulator for frequency or phase modulated signals that requires no limiter stage but it is not presently used in carrier equipment now employed in telephone systems.

HYBRID CIRCUITS

8.01 Hybrid circuits of various types are used in both trunk and subscriber carrier terminals for conversion of the two wire voice frequency drop, (tip and ring leads) which is commonly

used for both transmitting and receiving of voice frequency currents, into a separate two wire transmitting branch and a two wire receiving branch while providing a large transmission loss directly between these branches. The conversion from two to four wire operation at carrier terminals is necessary because the amplifiers, modulators, demodulators, etc., as are used in carrier transmitters and receivers operate in only one direction of transmission. Hybrid circuits are composed of one or more transformers or a network of resistors together with a voice frequency impedance balancing network. These components are interconnected in a manner somewhat resembling a Wheatstone bridge circuit and terminals are usually provided for the two wire drop, the transmitting branch, the receiving branch and the voice frequency impedance balancing network.

8.02 Hybrid circuits when properly balanced at each carrier terminal permit amplified voice frequency power in the receiving branches to be transmitted to telephone instruments, switchboards, or other trunks connected to the two wire drops with minimum loss, permit voice frequency power from the transmitters of telephone instruments connected to the two wire drops to be properly applied to the carrier transmitter modulators and simultaneously provide large transmission losses for any receiving branch power which enters the transmitting branch. This latter action aids in preventing undesirable hollowness or singing (oscillation) from occurring during carrier system operation. The prevention of singing will be further described in Par. 8.04.

8.03 Fig. 4 is a simplified schematic diagram showing transformer type hybrid circuit connections for a carrier channel operating between A and B. Although the hybrid circuits do not resemble schematically any type of bridge circuit they have been evolved from such an arrangement. The arrows show the directions of transmission at both voice and carrier frequencies. Voice frequencies to be transmitted from terminal A to terminal B, are coupled from the T and R leads to the transmitting branch at terminal A. They modulate the carrier frequency at transmitter T1 and the resultant modulated carrier frequency f1 is transmitted over the wire pair linking the terminals. At termina B demodulation takes place in the R1 receiver and the resultant voice frequencies are applied to the receiving branch of the hybrid terminal. The receiving branch connects with the T and R terminals in such a manner that when the balancing network at terminal B closely simulates the impedance of the circuit connected to the T and R terminals the voice frequencies are transmitted with a minimum loss in the desired direction of transmission (shown by solid arrow) while a large transmission loss occurs for received voice frequencies which enter the transmitting branch. Transmission between B and A, shown by the dashed arrows, takes place in a manner similar to that described above.

8.04 Singing will occur around the effective four wire portion of a carrier circuit such as shown in Fig. 4 (separate frequencies are used for both directions of transmission) if the sum of the amplification gains, around the four wire portion exceeds the sum of the transmission losses around this loop. In Fig. 4 the gains are provided by T1, R1, T2, and R2 while the losses are provided by the line connecting the carrier terminals and the losses between the receiving and transmitting branches of both hybrid circuits. The transmission losses at carrier frequencies on the line connecting the carrier terminals are a function of the type of open wire and cable facilities utilized and are overcome to a large extent by amplifiers. Variations in the losses of this line due to wet or dry weather conditions, sleet, temperature variations, etc. are sometimes compensated for by the use of carrier system regulators (Par. 9.) The transmission losses provided between the receiving and transmitting branches of each hybrid circuit, however, are a function of how well the balancing networks simulate the impedance of the circuits to which both of the voice frequency drops of the carrier terminals are switched, therefore it may be possible to achieve a large loss between these branches when they are switched to certain voice frequency lines and very low losses, with the possible danger of hollowness or singing effects, when switched to other lines. Since the impedance variations between voice frequency lines may be substantial it is not possible to design one balancing network whose impedance will simulate all the impedances encountered, therefore a compromise impedance balancing network is usually provided in most carrier systems.

8.05 It is further desirable in carrier system operation that the sum of the losses around the four wire portion of the circuit exceed the sum of the gains even under the worst possible conditions of hybrid balance that may be encountered. This requirement, while guarding against any possibility of hollowness or singing, usually results in the adjustment of the various gain controls of the carrier system in such a manner that it operates at an overall voice frequency net loss even though the gain capabilities of the equipment would make it possible under conditions of better hybrid balance to operate at lower voice frequency net losses, at zero net loss or even possibly at a net gain.

8.06 As an example of a carrier channel operating at a voice frequency net loss of 4 db, such as might be encountered in certain trunk carrier applications, again consider the system shown in Fig. 4. If a 1000 c.p.s. tone at a power of 0 dbm (1 milliwatt in 600 ohms) were applied to the T and R leads at carrier terminal A and the various gain controls in T1 and R1 were adjusted so that the reproduced 1000 c.p.s. tone is applied to a 600 ohm resistor connected to the T and R leads at terminal B at a power of -4 dbm the carrier channel would be operating at a 4 db net loss in the A to B direction. Similar adjustments in the opposite direction of transmission

usually would be made so that the system operates with a 4 db net loss in both directions of transmission. With the carrier system adjusted as described above singing would probably not occur even under the worst conditions of hybrid balance that may be encountered.

9. CARRIER SYSTEM REGULATION

9.01 Whenever trunk or subscriber carrier channels are installed and functioning properly the various gain controls have usually been adjusted in such a manner that these channels are operating at a voice frequency net loss. This procedure, as described previously, guards against the possibility of hollowness or singing taking place during conditions of poor hybrid balance. When the carrier frequency attenuation of the wire pair connecting the carrier terminals varies as a result of wet or dry weather conditions, sleet or ice forming on open wire lines, temperature changes, line leakage changes, etc., the voice frequency net loss will also vary as a result of this attenuation variation unless some form of regulator is used to adjust the system gains so as to compensate for this variation.

9.02 As a quantitative example consider a situation where an open wire carrier derived trunk is operating at a net loss of 4 db when the dry weather attenuation of the open wire circuit at the carrier frequencies utilized is 18 db. Assume that when wet weather, sleet, etc., occurs the attenuation of this circuit at these carrier frequencies increases by 6 db, with the voice frequency net loss then becoming 10 db. In some trunk applications this net loss may be excessive and would result in a poor grade of transmission until such time that the line attenuation decreased to its original value of 18 db.* Where carrier system regulation is utilized in a similar situation, however, the regulators at both terminals will automatically control the receiver gains in such a manner that the 4 db net loss will remain substantially constant as long as the range over which the regulator will effectively function is not exceeded.

9.03 Carrier system regulation is usually accomplished optionally for carrier channels employing single sideband suppressed carrier modulating techniques by transmitting a reference power at carrier frequencies from both terminals. This reference power is usually received, amplified and converted to a D.C. voltage which controls the carrier receiver gains so as to compensate for line attenuation variations. If the line attenuation increased, for example, less reference

---

*In non-regulated carrier systems the various gain controls on the carrier equipment could probably be readjusted to improve transmission for this situation but whenever the line losses decreased to their original value these controls would again require readjusting to prevent singing from occurring.

power would be received at a carrier terminal. This would result in the development of a smaller D.C. control voltage which would, in turn, cause an increased amplifier gain to compensate for the increased line attenuation. Transmitted reference powers can be the carrier frequencies themselves transmitted at reduced levels, or they can be separate frequencies in the carrier portion of the spectrum. These separate frequencies are sometimes referred to as pilot channel frequencies.

9.04 Carrier system regulation is provided in some systems which utilize transmitted carrier techniques by amplifying the received carrier frequencies and converting them to D.C. control voltages in a manner similar to that given in Par. 9.03.

9.05 Carrier system regulation in frequency or phase modulated systems is inherently provided if saturation of the amplitude limiters can occur. (Par. 7.05 and 7.06) If the carrier frequency attenuation of the line connecting the carrier terminals is not of sufficient magnitude to prevent limiter saturation no amplitude variations (which are a function of line attenuation) are passed on to the discriminator circuit. Therefore, if limiting occurs, the discriminator circuits and hence the voice frequency net losses are not subject to the attenuation variations of lines at carrier frequencies.

10. COMPANDORS*

10.01 Compandors are electronic devices available either optionally or as a built-in feature in some types of carrier equipment to economically reduce noise and crosstalk effects in situations where more than one carrier system with similar frequencies is operating over the same route. Compandor advantage can be expressed as increased crosstalk loss.

10.02 As a quantitative example consider the situation where the measured far end crosstalk coupling loss between two wire pairs is 40 db at the carrier frequencies to be utilized and like carrier channels are to be superimposed on both of these wire pairs. With non-compandored carrier systems this crosstalk loss is probably not sufficient to prevent intelligible crosstalk from occuring between these carrier systems. If, however, compandored carrier systems are utilized on these wire pairs the compandor advantage in db can be added to the far end crosstalk coupling loss. With an assumed compandor advantage of 20 db in this example, the far end crosstalk coupling loss is effectively increased to 60 db, thereby preventing objectionable intelligible crosstalk between the two carrier systems.

---

* "A Minature Compandor for Ge
Systems" by F. S. Boxall ar
Electronics, No. 10, Januar

10.03 The use of compandors on carrier systems may result in the possibility of utilizing one or more higher frequency carrier systems on an open wire route transposed for operation of lower frequency carrier systems only, since compandor advantage can be translated into a certain relaxation in transposition requirements.

10.04 A compandor circuit for one direction of transmission consists of an electronic volume compressor circuit connected between the voice frequency input and the modulator circuit and an expandor circuit connected between the demodulator circuit and the voice frequency output at the opposite terminal. Strong voice frequencies pass through the compressor, into the modulator, over the wire pair to the opposite terminal as modulated carrier frequencies, into the demodulator, and through the expandor with little gain or loss attributable to the compandor. Weak voice frequencies, however, are amplified considerably in the compressor and attenuated a like amount in the expandor. This amplification of weak voice frequencies, so that they are transmitted over the carrier portion of the circuit (between the compressor and expandor) at a higher level than intervening noise or crosstalk currents superimposed upon the wire pair linking the carrier terminals partially accounts for the transmission advantage obtained from compandor operation. In addition during idle conditions, such as a pause in the receiving conversation when interfering effects would be particularly annoying the action of the expandor circuit is such that it presents a high attenuation (expandor loss for weak signals) to the intervening noise and crosstalk induced into the carrier circuit. Compandor action in the opposite direction of transmission is performed in a manner similar to that described above.

11. CARRIER REPEATERS

11.01 Carrier repeaters, available for certain types of long-haul trunk and subscriber carrier equipment, are electronic devices capable of amplifying carrier currents so a overcome high transmission losses between term application situations where the exceed the maximum recommended values for the particular carrier terminal equipment utilized or where non-coterminus[1] carrier channels must have their levels balanced for crosstalk reduction reasons. (Par. 15.06) Some types of carrier repeaters are available for amplifying carrier frequencies on an individual channel basis while other types are available

[1] Where two or more separate carrier terminal locations are such that their carrier currents must share portions of the same route in connecting with another carrier terminal location.

for simultaneously amplifying carrier frequencies of a group of channels. Both regulated and non-regulated types of repeaters are available.

11.02 Carrier repeaters usually consist of line filters, bandpass filters for separating the two directions of transmission, separate amplifiers for both directions of transmission, and the proper type of power supply. No signaling or hybrid terminations are required since demodulation to voice frequencies usually does not occur. In one type of repeater a modulator arrangement is provided in order to permit "frequency frogging."

11.03 In a frequency frogged type of repeater a group of low frequencies representing the carrier information from several channels transmitted in one direction enters the carrier repeater where it is translated to a higher position in the carrier frequency spectrum by a modulator, amplified and then retransmitted to the next repeater or carrier terminal as a group of high frequencies. Similarly the group of high frequencies entering the repeater from the opposite direction are translated to a low group position for retransmittal to the next carrier repeater or terminal as a low group of frequencies. The translation from high to low and low to high frequencies at such repeaters (frogging) reduces the effects of interaction* crosstalk in some situations while extensive slope equalization** and slope regulating networks do not need to be provided in the repeater since the normal variation of line attenuation with frequency is equalized in an even number of repeater sections, assuming equal spacings, weather conditions, etc.

11.04 The East-West and West-East conventions for directions of transmission normally utilized in carrier equipment do not readily apply to carrier equipment employing frequency frogging due to the interchange of groups of frequencies at each repeater location.

12. CARRIER POWER SUPPLY CONSIDERATIONS

12.01 In order to provide power for the various electronic circuits needed in carrier equipment it is necessary to supply direct currents at various voltages to tube elements such as cathodes, grids, plates and various relays and either direct or alternating

---

*Crosstalk resulting from mutual coupling between two paths by means of a third path.

**An arrangement whereby more amplification is provided at higher carrier frequencies than at lower carrier frequencies due to the increase in attenuation of the transmission line as a function of frequency.

currents for the tube filaments. Completely transistorized equipment requires only direct currents at various voltages for the transistor elements since no filament power is needed.

12.02 Common methods of powering trunk carrier terminals under normal operating conditions (equipment not on standby power) are summarized in the following paragraphs.

12.021 Filament and plate power (power to all tube elements except filaments will be considered as plate power) both supplied from a nominal 117V 60 c.p.s. source. The filament power is provided at a low AC voltage by means of a step-down transformer operated from the AC line. The plate power is also supplied from the AC line by means of a step-up transformer together with vacuum tube or metallic rectifiers and the proper filtering components.

12.022 Filament power supplied from a 24 or 48V central office battery and 130V DC plate power supplied from a 117V 60 c.p.s. source by means of suitable transforming, rectifying and filtering components.

12.023 Filament power supplied from 24 or 48V central office battery and 130V DC plate power supplied from an additional bank of plate supply batteries charged by a rectifier.

12.024 Filament and plate power both supplied from the 48V central office batteries.

12.03 Some trunk carrier systems can be wired optionally so that filament and plate power can be supplied from batteries or from commercial alternating current sources while other carrier systems can be powered from only the latter source with no wiring options.

12.04 Common methods of powering central office terminals of subscriber carrier systems under normal operating conditions (equipment not on standby power) are the same as those described in Par. 12.021 and 12.024 above.

12.05 The common method of powering subscriber (remote) terminals of subscriber carrier equipment or central office terminals of such equipment (in situations where it is necessary to provide mounting arrangements external to the central office under normal operating conditions) is as given in Par. 12.021 above.

12.06 Where standby power is to be provided for trunk and subscriber carrier systems the type of standby equipment to utilize will depend upon how the channel terminals are normally powered. Standby power equipment would be necessary for carrier terminals normally powered by the methods given in Par. 12.021 and 12.022. Terminals normally powered from batteries such as described in Par. 12.023 and 12.024 would need no additional equipment for operation under standby conditions. In order to prevent depletion of the desired busy hour reserve for central office batteries due to the operation of carrier equipment from these sources during standby conditions it is necessary that the total additional current drains of carrier terminals and conversion equipment be considered in the central office battery requirements.

12.07 Where carrier terminals are powered from commercial alternating current sources whose voltages vary over wide limits automatic voltage regulators may be required in order to assure long vacuum tube life. These regulators are usually supplied as optional equipment for carrier terminals.

13. CARRIER SIGNALING

13.01 In addition to its ability to simultaneously transmit voice frequencies in both directions, a carrier system must also provide the necessary features for transmitting and receiving the proper signaling information in both directions for initiating or terminating a telephone connection.

13.02 Signaling functions for trunk carrier systems are necessary for transmitting and receiving off-hook and on-hook signals, dial pulses, and various supervisory tones so that proper telephone connections can be established between central offices.

13.03 Signaling functions for subscriber carrier systems are necessary for transmitting and receiving off-hook and on-hook signals, dial pulses, the information for selecting the proper side of the subscriber line to which ringing power is to be applied, the application of ringing power at the correct ringing frequency at the remote subscriber terminals and various supervisory tones so that telephone connections can be established between remote subscribers' telephone sets and the central office.

13.04 Off-hook, on-hook, dial pulsing, and ringing functions such as described above are generally transmitted and received over carrier systems by any of the following methods or combinations of these methods:

13.041 Out-of-band voice frequency tones keyed on or off (frequencies above approximately 3400 c.p.s.) to modulate the carrier frequencies.

13.042 In-band voice frequency tones keyed on or off to modulate the carrier frequencies. (Frequencies below above 3400 c.p.s.)

13.043 Frequency shifting of in-band or out-of-band voice frequency tones or the carrier frequency itself. These tones, as well as those mentioned above, are sometimes further utilized for carrier system regulation. (See Par. 9)

13.044 Interruption (keying on and off) of transmitted carrier frequencies.

13.045 By utilizing separate carrier frequency transmitters and receivers whose operating frequencies do not conflict with those of the carrier terminals or carrier system regulators.

13.05 Supervisory tones originating in the various central offices can usually be transmitted simultaneously at voice frequencie in both directions over the carrier system itself, except for certain types of trunk and subscriber line carrier equipment utilizing carrier interruption techniques for off-hook and dial pulse signals where simultaneous signaling in both directions of transmission is not required.

13.06 In-band or out-of-band voice frequency tones are usually generated by voice frequency electronic oscillators which are part of the carrier terminals. They are used for modulat ing the carrier frequency oscillator in a manner similar to voice modulation (either amplitude or frequency) in accordanc with the on-hook, off-hook, dial pulse or ringing information to be transmitted over the carrier system. These tones can be keyed on or off when the carrier circuit is in either the idle or talking condition, depending upon the carrier system utilized and the connections desired for operation with the central office equipment.

13.07 At the carrier receiver located at the opposite terminal of the system the tones described in 13.06 are demodulated, amplified, and converted to D.C. control voltages so that they cause a signaling or a ringing relay to operate at the carrier terminal. This relay, in turn, operates relays in the central office trunking equipment or line circuits in accordance with the signaling information transmitted or, in the case of remote subscriber line carrier terminals, applies the generated ringing frequency power to the proper side of the line to ring the called subscriber's telephone.

13.08 Most trunk carrier systems are normally supplied with built-in signaling functions for operating with central office trunk circuits wired for E and M lead signaling. (REA-TE & CM Section 319) If trunk circuit terminations other than those for ringdown trunks or E and M lead signaling are to be utilized at central offices special pulse link circuits might have to be supplied to convert from E and M lead signaling to the type of signaling required for the central office trunking equipment.

13.09 Most subscriber line carrier systems are normally supplied with built-in signaling functions for operating with conventional two wire dial or common battery manual telephone sets equipped with high impedance ringers connected either on a bridged or divided arrangement and conventional dial or common battery manual central office line circuits. Examples of signaling functions are given in Par. 14.

14. CARRIER SYSTEM OPERATION

14.01 The previous paragraphs of this section have briefly described some of the principle components from which a carrier system is assembled. The following paragraphs will describe the manner in which voice and carrier frequencies are transmitted by means of a carrier channel consisting of these components, E and M lead signaling by means for a trunk carrier channel, and dialing and full selective ringing functions for a subscriber carrier channel.

14.02 Fig. 5 shows in block diagram form one carrier channel without signaling superimposed on a wire pair between A and B. This wire pair is to be used as a transmission medium for the basic physical circuit as well as the carrier derived voice circuit, therefore line filters are connected as shown.

14.021 Voice frequencies to be transmitted by means of the physical circuit between A and B appear at the T and R leads of this circuit at A and are transmitted with a minimum loss through the low pass section of this line filter along the wire pair connecting the two locations, through the low pass section of the line filter at B with a minimum transmission loss and appear at the T and R leads of this physical circuit at B. Transmission by means of the physical circuit between B and A takes place in a similar manner. The line filter permits the use of both voice and carrier frequencies on the wire line without interaction, as explained in Par. 2.03.

14.022 Currents at voice frequencies to be transmitted over the carrier system between A and B, are applied to the T and R leads of the voice frequency drop connected to the hybrid circuit at Terminal A. They

are coupled to the transmitting branch so as to reach the modulator stage with the proper magnitude for the correct percentage of modulation. At the modulator stage the voice frequencies, assuming they range from 250 to 2800 c.p.s., are mixed with a 10 KC carrier frequency for this example. Sidebands are generated as explained previously and, depending upon the modulating technique utilized, various combinations of sidebands with or without the presence of the carrier frequency appear at the modulator output, as f1. In this example it is assumed that the single sideband suppressed carrier technique is utilized with the lower sideband to be transmitted. This sideband, extending from 7.2 KC to 9.75 KC is amplified by the carrier frequency amplifier and then passed through the transmitting bandpass filter and the high pass section of the line filter with a minimum attenuation before reaching the carrier line. After transmittal over the carrier line to Terminal B this sideband is passed through the high pass section of the line filter and the receiving bandpass filter before being amplified. After carrier frequency amplification the sideband enters the demodulator stage where it is mixed with a 10 KC locally generated carrier frequency. Among the resultant products of demodulation is the original voice frequency band which was transmitted at Terminal A. (Par. 7.03) Currents of voice frequencies are then amplified before entering the receiving branch of the hybrid network. They are then coupled to the two wire voice frequency drop by means of the hybrid circuit at B.

14.023 Voice transmission from Terminal B to Terminal A takes place in a similar manner to that described in Par. 14.022 except that a different carrier frequency (f2) is used together with transmitting and receiving bandpass filters whose passbands match the desired sideband to be transmitted. Therefore, transmission from Terminal B to Terminal A takes place over the same wire pair as that from Terminal A to Terminal B, but it is in a completely different frequency range so as to preclude any interference from unwanted oscillations or other effects which would result in various forms of distortion.

14.024 Although Fig. 5 shows only one carrier channel superimposed upon a basic physical circuit it is possible to stack a number of channels with different

carrier operating frequencies upon a wire pair in a similar manner. The main difference between each stackable channel is in the operating frequencies and the bandpass filters utilized. Other stackable carrier channel terminals are usually bridged across the terminal side of the high pass section of the line filters as shown in Fig. 5.

14.025 Carrier signaling over the one channel system shown in Fig. 5 can take place by any of the methods given in Par. 13.04 depending upon whether the carrier system is for trunk or subscriber usage.

14.03 An example of trunk carrier operation with E & M lead signaling and separate carrier frequency transmitters and receivers for signaling purposes (Par. 13.045) is given below. Fig. 6 shows a basic carrier system as described in Par. 14.02 together with the separate signaling transmitters and receivers. For signaling over the carrier system from terminal A to B the calling party seizes the trunk equipment (REA-TE & CM, Section 319) and energizes the D relay connected to the M lead at carrier terminal A. Closing the circuit into the transmitting oscillator and amplifier at this location can either turn on or turn off signaling frequency f3, depending upon whether the carrier system is to employ "tone on" or "tone off" during the idle condition. Assuming that "tone on when idle" is employed the energization of the D relay turns off carrier current at the f3 frequency. At the signaling receiver at Terminal B this loss of f3 signal from Terminal A actuates relay C and places ground on the E lead, which connects with the trunk equipment. Actuating the trunking equipment in the central office associated with the A carrier terminal and subsequent dialing causes relay D to be pulsed in accordance with the desired numbers to be dialed. This action causes the signaling transmitter frequency f3 to be pulsed on and off at the dialing rate and this information, in turn, is transmitted to B. At B the pulsing of f3 operates relay C at the dialing rate and alternately grounds and ungrounds the E lead connected to the trunking equipment at this central office. This action pulses the appropriate relays in this central office and completes the connection to the called party. Either ringback tone or a line busy signal are now transmitted from B to A over the T and R leads of the carrier channel. Whenever the called party places his telephone in the off-hook condition the central office equipment at B energizes relay G in series with the M lead which, in turn, operates relay H at Terminal A thus grounding the E lead to the trunk equipment and returning answer supervision to the calling office. A call from B to A is made in a similar manner to that described herein.

14.031 Trunk carrier channels can also be obtained for ringdown signaling applications and for special terminations, but since E & M lead signaling is becoming increasingly important and receiving widespread use in the REA program no explanation of other methods of trunk carrier signaling is given to this section.

14.04 An example of subscriber carrier signaling using full selective ringing and dialing to the central office is given below: Fig. 7 shows a basic carrier system such as described in Par. 14.02 together with the required signaling functions to permit dialing from the subscriber terminal to the central office and full selective ringing from the central office to remote subscribers.

14.041 For dialing over the carrier system a remote subscriber connected to the T and R leads at the subscriber terminal places his telephone in the off-hook condition in the normal manner. This action causes current from the built-in 48 volt talking battery supply of the terminal to energize relay A. Contact 1 associated with this relay closes and permits carrier current at frequency f1 to be transmitted from the subscriber terminal to the central office terminal of the channel. The receipt of carrier current at the demodulator (the receivers are on at all times) causes the signaling amplifier to actuate relay D which completes a D.C. path through contacts 2 and 4 and the hybrid network so as to connect T and R to the central office equipment. Either dial or all links busy tone now appears at the T and R leads of the central office terminal. Since the carrier transmitter at this terminal is assumed to be energized at all times, these tones are transmitted to the subscriber terminal in a manner similar to that described in Par. 12.023. If dial tone is received at the subscriber terminal the calling subscriber now begins dialing the desired number. Relay A follows the dial pulses and alternately transmits and interrupts the f1 carrier frequency by the action of contact 1 in accordance with the opening and closing of the subscriber loop by the dial pulses that are transmitted. At the central office terminal relay D is actuated in accordance with the pulsing incoming carrier frequency current, and causes pulsing of the central office switching equipment. After dialing is performed either a busy or ringback signal is transmitted from the central office to the calling subscriber. Whenever the

called subscriber answers his telephone the two way carrier talking circuit functions in the normal manner. Upon completion of a call the carrier frequency current transmitted from the subscriber terminal ceases whenever the remote subscriber that had previously been utilizing the carrier system places his phone in the on-hook condition. This action disconnects the line circuit at the central office associated with the carrier channel since the contacts on relay D again resume the position shown in Fig. 7.

14.042 Ringing from the central office to a remote carrier subscriber whose telephone ringer is connected between the R side of the line and ground is explained in this paragraph. Assume the relays associated with the subscriber carrier channel are in the position shown in Fig. 7. All phones connected to the subscriber terminal are in the on-hook condition and there is no completed d.c. path between the central office terminal of the carrier channel and the line circuit in the central office. A subscriber on another line in the central office or a subscriber in another office dials the number of a subscriber connected to the subscriber terminal of the carrier channel. Assume that this called subscriber has a 30 c.p.s. ringer in his telephone set and that this ringer is connected between the R side of the line and ground. The ringing equipment located in the central office will apply 30 c.p.s. power between R side of the line and ground at the central office terminal and will also ground the T side of the line while ringing is occuring. This ringing current flows through Contact 1 on the D relay to a pad where it is attenuated sufficiently so as to provide the proper degree of modulation at carrier frequency f2 when applied together with the output of tone oscillator f5 (applies power through contact 5 of the D relay) to the modulator stage. The f2 carrier frequency, modulated simultaneously by the 30 c.p.s. ringing frequency and the f5 tone oscillator is transmitted to the subscriber terminal of the carrier channel in the normal manner. At the subscriber terminal the demodulation process separates the 30 c.p.s. ringing frequency and the f5 tone oscillator frequency from the carrier frequency. The ringing power output stage of this carrier terminal amplifies the 30 c.p.s. power to a magnitude sufficient for operating conventional high impedance telephone

called subscriber answers his telephone the two way carrier talking circuit functions in the normal manner. Upon completion of a call the carrier frequency current transmitted from the subscriber terminal ceases whenever the remote subscriber that had previously been utilizing the carrier system places his phone in the on-hook condition. This action disconnects the line circuit at the central office associated with the carrier channel since the contacts on relay D again resume the position shown in Fig. 7.

14.042 Ringing from the central office to a remote carrier subscriber whose telephone ringer is connected between the R side of the line and ground is explained in this paragraph. Assume the relays associated with the subscriber carrier channel are in the position shown in Fig. 7. All phones connected to the subscriber terminal are in the on-hook condition and there is no completed d.c. path between the central office terminal of the carrier channel and the line circuit in the central office. A subscriber on another line in the central office or a subscriber in another office dials the number of a subscriber connected to the subscriber terminal of the carrier channel. Assume that this called subscriber has a 30 c.p.s. ringer in his telephone set and that this ringer is connected between the R side of the line and ground. The ringing equipment located in the central office will apply 30 c.p.s. power between R side of the line and ground at the central office terminal and will also ground the T side of the line while ringing is occuring. This ringing current flows through Contact 1 on the D relay to a pad where it is attenuated sufficiently so as to provide the proper degree of modulation at carrier frequency f2 when applied together with the output of tone oscillator f5 (applies power through contact 5 of the D relay) to the modulator stage. The f2 carrier frequency, modulated simultaneously by the 30 c.p.s. ringing frequency and the f5 tone oscillator is transmitted to the subscriber terminal of the carrier channel in the normal manner. At the subscriber terminal the demodulation process separates the 30 c.p.s. ringing frequency and the f5 tone oscillator frequency from the carrier frequency. The ringing power output stage of this carrier terminal amplifies the 30 c.p.s. power to a magnitude sufficient for operating conventional high impedance telephone

ringers. At the same time a d.c. bias voltage, derived from the demodulation of the carrier frequency is applied to the Ringing Relay Circuit and utilized to operate the C relay. This relay switches the T and R leads to contacts 4 and 2, respectively, and applies the 30 c.p.s. ringing power between either the T or R leads and ground, depending upon the position of the contacts associated with relay B. The position of the contacts of relay B will remain as shown in Fig. 7 as long as the f5 tone oscillator power is being received. Therefore each time that the 30 c.p.s. ringing power is applied between the R side of the line and ground at the central office terminal of the carrier equipment the 30 c.p.s. power is reproduced at the subscriber terminal and relay C applies this power between the R side of the line and ground while grounding the T side since relay B is not operated. The action of these relays must be sufficiently fast so as not to shorten the duration of "short rings" when ringing codes are utilized. This ringing will continue until the called subscriber places his phone in the on-hook condition, the calling subscriber hangs up or the circuit times out. Ringing power of any other frequency applied between the R side of the line and ground at the central office carrier terminal would also be reproduced and applied to the R side of the line at the subscriber terminal in a similar manner.

14.043 Ringing from the central office to a remote carrier subscriber whose telephone ringer is connected between the T side of the line and ground is explained in this paragraph. Assume the relays associated with the subscriber carrier channel are in the position shown in Fig. 7. All phones connected to the subscriber terminal are in the on-hook condition and there is no completed d.c. path between the central office terminal of the carrier channel and the line circuit in the central office. A subscriber on another line in the central office or a subscriber in another office dials the number of a subscriber connected to the subscriber terminal of the carrier channel. Assume that this called subscriber has a 40 c.p.s. ringer in his telephone set and that this ringer is connected between the T side of the line and ground. The ringing equipment located in the central office will apply 40 c.p.s. power between the T side of the line and ground at the central

office carrier terminal and will also ground the R side of the line while ringing is occurring. This ringing current flows through contact 3 on the D relay to a pad where it is attenuated sufficiently so as to provide the proper degree of modulation at carrier frequency f2. In addition, a portion of this ringing current flows through capacitor C to d.c. relay E where it is rectified and used for energizing this relay. Operation of relay E results in the disconnection of the f5 tone oscillator from the modulator stage. Therefore the f2 carrier frequency, modulated by only the 40 c.p.s. ringing frequency, is transmitted to the subscriber terminal of the carrier channel in the normal manner. At the subscriber terminal the demodulation process separates the 40 c.p.s. ringing frequency from the carrier frequency. The ringing power output stage of this carrier terminal amplifies the 40 c.p.s. power to a magnitude sufficient for operation of conventional telephone ringers. At the same time a d.c. bias voltage, derived from the carrier demodulation process, is applied to the Ringing Relay Circuit and utilized to operate the C relay. This relay switches the T and R leads to contacts 4 and 2, respectively, and applies the 40 c.p.s. ringing power between either the T and R leads and ground, depending upon the position of the contacts associated with relay B. Relay B now operates due to the absence of f5 tone at the Ringing Selector Circuit shown in Fig. 7. When Relay B operates due to the absence of the f5 tone frequency the position of the contacts associated with it will switch so that the T side of the line will now be connected through contact 3 on this relay to the ringing power output while the R side of the line will be connected to ground by means of contact 2. Therefore each time that the 40 c.p.s. ringing power is applied between the T side of the line and ground at the central office terminal of the carrier equipment the f5 tone is turned off and the 40 c.p.s. power modulates the carrier frequency and is reproduced at the subscriber terminal. Relay C then applies this power between the T side of the line and ground since relay B was made to operate by turning off the f5 tone in the central office terminal. Ringing power of any other frequency applied between the T side of the line and ground at the central office carrier terminal would also be reproduced and

applied to the T side of line at the subscriber terminal in a similar manner.

14.044 The action of relay E in the central office terminal and relays B and C in the subscriber terminal must be sufficiently fast so as not to shorten the duration of "short rings" when ringing codes are utilized. However, the T or R selection of the line at the subscriber terminal for ringing must be made before ringing power is actually applied to the line so that this power will only be applied to the desired side of the line. This prevents bell tapping and other undesirable effects in full selective ringing systems.

14.045 In order to provide ring tripping with the signaling system described herein the called subscriber connected to the subscriber terminal of the carrier system whose phone is ringing places his phone in the off-hook condition. Since at the cessation of each application of ringing power relay C assumes the position shown in Fig. 7, a phone in the off-hook condition will then actuate relay A which opens contact 2 of this relay to disconnect the demodulator output to the ringing system of the carrier terminal thus preventing any further operation of the ringing power output and relays B and C. This action prevents any further application of ringing power to the line connected to the subscriber terminal. At the same time, the actuating of relay A also permits the transmittal of carrier frequency current to the central office terminal which, as described previously (Par. 12.041) actuates relay D and provides a.d.c. path for the T and R leads into the switching equipment thereby tripping the ring in the central office in the normal manner. This action of relay D also disconnects the pads, relay E and the f5 tone oscillator from the modulator circuit whenever the subscriber carrier channel is in talking condition. This type of ring tripping only operates during the silent interval between successive applications of ringing power. Other subscriber carrier systems are available to provide instantaneous ring tripping during any portion of the ringing cycle, if desired.

14.046 Revertive calling by subscribers connected to the far terminal of the subscriber carrier channel is handled in the normal manner by the central office

switching equipment. No special telephone sets or ringing arrangements in the central office are needed for revertive calls handled by this type of carrier system.

14.05 The above brief descriptions of two possible methods of operating trunk and a subscriber carrier channels is given for information purposes only in these examples and do not represent any preferred methods for providing such operational features.

15. CARRIER TRANSMISSION CONSIDERATIONS

15.01 Carrier transmission is a very complex subject and it is only possible to discuss some of its more general aspects in this section. The greater attenuation of various types of wire facilities at carrier frequencies and the increased possibilities for crosstalk due to the use of frequencies higher than those used for voice transmission together with the higher gains afforded by electronic amplifying equipment in carrier receivers provide some of the complexities associated with this type of transmission. On the other hand, properly engineered carrier facilities usually supply derived circuits with adequate voice frequency response and a minimum of circuit noise.

15.02 In carrier transmission DBM values are usually used to measure power transmitted and received. Zero level in DBM is referenced to a power of 1 milliwatt developed in a 600 ohm load. Plus values of dbm indicate a power greater than zero reference level (1 milliwatt) while minus values of dbm indicate a power less than 1 milliwatt.

15.03 As an example of powers used in a carrier system assume that a 1000 c.p.s. test tone at 0 dbm (1 milliwatt in 600 ohms) is applied to the two wire voice frequency drop of Terminal A shown in Figure 5. Again assuming a single sideband suppressed carrier modulating technique this test tone would modulate the carrier frequency and provide a carrier frequency sideband for transmission over the wire facilities. This sideband would appear on the line side of the line filter at Terminal A with a power of $+$ 15 dbm. While being propagated to Terminal B the sideband is attenuated 35 db by the wire facilities. This attenuation depends upon the loss at carrier frequencies of the various facilities over which the carrier currents are transmitted. (Par. 15.042) It therefore arrives as received power of -20 dbm at the line side of the line filter at this terminal. It is assumed that this received power is within the minimum allowable

for the type of carrier equipment utilized. This sideband then enters the carrier receiver where it is amplified at carrier frequency, demodulated, and the resultant 1000 c.p.s. test tone is then amplified at voice frequency and appears at the two wire voice frequency drop at a power of -4 dbm. From this example it can be seen that the test tone received a transmitting gain of 15 db, a receiving gain of 16 db, and an attenuation at carrier frequencies of 35 db. Even though the attenuation of the wire facilities at carrier frequencies was 35 db it was still possible to derive a circuit whose overall net loss at 1000 cps was only 4 db. The overall net loss can usually also be varied upward or downward by means of the controlled electronic amplification provided by the carrier equipment in order to meet the desired net loss requirements for the particular carrier derived circuits.
(See Par. 6.05)

15.04 The maximum length of line facilities over which it is possible to transmit carrier currents and still maintain adequate speech-to-noise ratios between carrier terminals, between terminals and adjacent repeaters or between repeaters depends upon the particular type of carrier equipment used and the total attenuation of the line facilities.

15.041 Some of the factors pertaining to the equipment itself which affect carrier transmission are summarized below:

1. The type of modulating technique utilized.
2. The maximum transmitting output.
3. The minimum receiving input so as to assure an adequate speech-to-noise ratio.
4. Whether or not any form of automatic gain control is used.
5. Whether or not compandors are used.
6. The filter arrangements used on the particular carrier circuit.
7. Level settings for minimizing crosstalk in situations where more than one carrier system with similar operating frequencies and sidebands shares a portion of the same wire circuit route or routes. Level coordination is discussed in greater detail in Par. 15.06.

8. The carrier and voice frequency balance to ground for carrier terminals and associated filters.

15.042 Some of the factors pertaining to the line facilities which affect carrier transmission are summarized below:

1. The attenuation at carrier frequencies of the open wire pair or pairs during various conditions of weather and temperature.

2. The attenuation of cable pairs at carrier frequencies during various conditions of temperature.

3. Impedance mismatches between different types of wire facilities.

4. The amount of carrier frequency noise which may be present on this wire pair during various times of the year. This noise can be due to summer static, precipitation static or electric supply transmission lines.

5. The amount of crosstalk loss achievable by the transposition system on the open wire routes and between the cable pairs in situations where more than one carrier system with similar operating frequencies and sidebands shares all or a portion of the same open wire and cable route.

6. Increases in attenuation attributable to absorption peaks* in some situations where carrier channels are operated at frequencies higher than those for which the transposition system was designed to function properly.

7. Increases in attenuation attributable to untreated open circuited taps on open wire or cable pairs used for carrier transmission. This situation, which can frequently occur in subscriber carrier layouts, should be prevented by means of the proper filter or termination arrangement.

15.043 As an example of a carrier system transmission calculation consider a situation where it is planned to operate a three channel trunk carrier system,

---

*An excessive transmission loss at a particular frequency or range of frequencies relatively close to this frequency caused by crosstalk coupling into surrounding wires or earth and back again in a phase which opposes the original transmission.

whose top frequency is 40 KC, between central offices A and B, which is a distance of 25 miles. It is planned that the carrier circuit will consist of one mile of 22 gauge paper insulated non-loaded entrance cable connected to each central office and 23 miles of 080 CW 30% conductor transposed to the R1 system with 12 inch spacing between wires. Referring to Table I of Section 406 of the REA TE & CM it is seen that the attenuation of each length of entrance cable at 40 KC is 7.3 db/mi. Referring to Table II of Section 406 it is seen that the wet weather attenuation of the open wire portion of the circuit at 40 KC is 0.42 db/mi. If impedance matching devices are used between the carrier terminals and the entrance cables as well as between the entrance cables and the open wire pairs losses due to reflections are minimized but these devices as well as line filters also introduce some loss at carrier frequencies. Therefore the total calculated wet weather loss at 40 KC for the circuit between central offices A and B is summarized below:

1 mi. 22 ga. cable at 7.3 db/mi.	=	7.3 db
23 mi. 080 CW 30% conductor at 0.42 db/mi.	=	9.7 db
1 mi. 22 ga. cable at 7.3 db/mi.	=	7.3 db
Assumed losses due to line filters and impedance matching devices at 40 KC		1.0 db
Total attenuation at 40 KC	=	25.3 db

The carrier system should meet transmission requirements if the total attenuation as given above does not exceed the manufacturer's recommended line loss at carrier frequencies for the particular type of equipment to be utilized. In this situation the transposition system is one that does not have any excessive absorption peaks in the planned carrier frequency range (REA-TE & CM Section 661, Addendum No. 1) and there are no taps on either the open wire or cable portions of the carrier route.

15.044 Impedance matching devices are used to minimize reflection losses caused by interconnecting two different types of conductors, such as cable conductors to open wire conductors. At carrier frequencies the characteristic impedance of 12 inch

spaced open wire copper or copper clad conductors is nominally 600 ohms while the characteristic impedance of cable pairs is nominally 135 ohms. If conductors such as mentioned above were interconnected without using impedance matching devices reflection losses would result and an uneven attenuation vs. frequency characteristic would occur over the wire facilities throughout the carrier frequency range. Adjustment of carrier system gains may compensate for this increased attenuation at certain carrier frequencies without the necessity for impedance matching. If more than one carrier system employing similar frequencies is operating on a wire route, however, impedance matching should be considered so as to reduce reflection effects which result in reflected near-end carrier crosstalk possibilities. Impedance matching is usually accomplished by the use of transformers having the proper turns ratio. These transformers are usually available for office mounting or in the same pole-mounted, electrically protected weatherproof housings used for line filters (Par. 2.014) in situations where impedance matching of cable and open wire circuits is a necessity.

15.05 Transposition systems are utilized on open wire routes to reduce line noise due to the inductive influence of power lines which may parallel the telephone route, to reduce noise due to atmospheric disturbances and to reduce voice or carrier frequency crosstalk caused by inductive effects of other circuits on the same telephone route. Assuming that the recommended maximum carrier frequency transmission loss is not exceeded between carrier terminals, between terminals and adjacent repeaters, or between repeaters the number of carrier channels that can be superimposed upon wire pairs arranged for a particular transposition system depends upon the following:

1. The far end crosstalk coupling loss achievable between various wire pairs at the operating frequencies of the carrier channels.

2. The number of frequency coordinated* ca utilized. This does not infer that nor dinated carrier systems cannot be utili

---

*Stackable carrier systems which utilize exactly the s and receiving frequencies. In addition some types of are available with one frequency allocation staggered a second frequency allocation so that these systems c the same route without mutual interference in situati crosstalk loss between coordinated systems may be ins

wire route since the crosstalk loss between certain wire pairs may be sufficiently high so as to permit such an application although the total number of carrier channels that could be provided under such an arrangement may be reduced somewhat.

3. Whether or not the carrier systems utilize compandors.

4. Whether or not significant absorption peaks are present in the frequency range of the carrier equipment to be utilized.

5. Whether or not level coordination is utilized for carrier channels sharing all or portions of the same open wire routes. See Par. 15.06.

15.051 Transposition systems for carrier operation usually utilize eight or twelve inch spacing between wires of a pair with either tandem or point type transposition brackets.

15.052 Various types of existing carrier transposition systems are usually effective for carrier systems whose top frequencies do not exceed 30 KC or 150 KC. 30 KC transposed lines are usually suitable for the proper operation of one or two additional compandored carrier systems whose top frequency does not exceed 150 KC. The new REA-1 transposition system described in Section 463 of the REA-TE & CM is suitable for operation of several carrier systems (either trunk or subscriber) at freauencies up to 350 KC.

15.053 Voice frequency transposition systems such as the R1 and R2, have several wire pairs upon which stackable carrier channels can be superimposed. Details as to the field of use of these transposition systems are given in Section 661 of the REA-TE & CM and Addendum No. 1 to that Section.

15.054 In situations where carrier channels are operated at frequencies higher than those for which the transposition system was designed absorption peaks will occur. The range of frequencies where significant increases in attenuation caused by absorption peaks are apt to occur depend upon the transposition intervals and the average span lengths of the open wire line. Addendum No. 1 to Section 661 of the REA-TE & CM provides information as to

where absorption peaks occur on some voice frequency transposition systems which are also sometimes used for carrier transmission. It is considered good practice to avoid the use of any carrier channels whose frequencies are subject to this effect since very high transmission losses can result over certain frequency ranges due to this phenomena.

15.06 Application situations sometimes arise where one or more carrier systems are superimposed upon portions of an open wire route together with other carrier systems with similar frequency allocations which use longer portions of this route. Such a situation is shown in simplified form in Fig. 8 for two carrier channels transmitting from locations A and C to location B. These application situations can also occur where the carrier equipment for the shorter circuit is located at location X in lieu of location C.

15.061 Situations such as described above can occur on trunk carrier routes, subscriber carrier routes or on combination trunk and subscriber carrier routes. The latter situation applies where portions of the trunk carrier route are also utilized for extending subscriber loops by means of subscriber carrier equipment.

15.062 With reference to Fig. 8 it is assumed that the same transmitting frequencies and power outputs are utilized for the carrier terminals at locations A and C, and that impedance matching is provided between these terminals and the entrance cables and between the entrance cables and the open wire routes. If, under the above conditions, the amount of power reaching location X from the carrier transmitter at the A location was measured during wet weather conditions it would be approximately -6.6 dbm. Similarly, if the amount of power reaching location X on the wire pair from location C was measured during the same weather conditions it would be approximately + 0.5 dbm. At location B the amount of power received from location A would be approximately -16.8 dbm, while the amount of power received from location C would be approximately -9.7 dbm, again assuming the same wet weather conditions. From the above it can be seen that under wet weather conditions there is a carrier level difference of approximately 7.1 db between the two wire pairs on

the portion of the route from X to location B. The dry weather level difference between these two circuits, assuming that the carrier transmitting powers, cable attenuation and impedance matching characteristics of the transformers, etc. remain unchanged, are a function of the open wire losses and would be approximately 6.8 db for this example. The variation in level differences between wet and dry weather conditions can thus be attributed to the lower attenuation of the open wire facilities during dry weather. Differences in attenuation in the cable circuits as a result of temperature changes may also contribute to level differences but were not considered in this example. It was further assumed in this example that both carrier routes were subject to the same wet or dry weather conditions throughout their entire length.

15.063 Level differences similar to those described above will also occur for other carrier channels operating on these routes in both directions of transmission. The magnitude of these level differences that will occur for various channels, assuming that the carrier transmitting powers and impedance matching characteristics of the transformers, etc. remain unchanged, are a function of the transmission losses of the cable and open wire facilities at carrier frequencies and will vary due to wet and dry weather effects upon open wire lines, temperature effects on cable, etc.

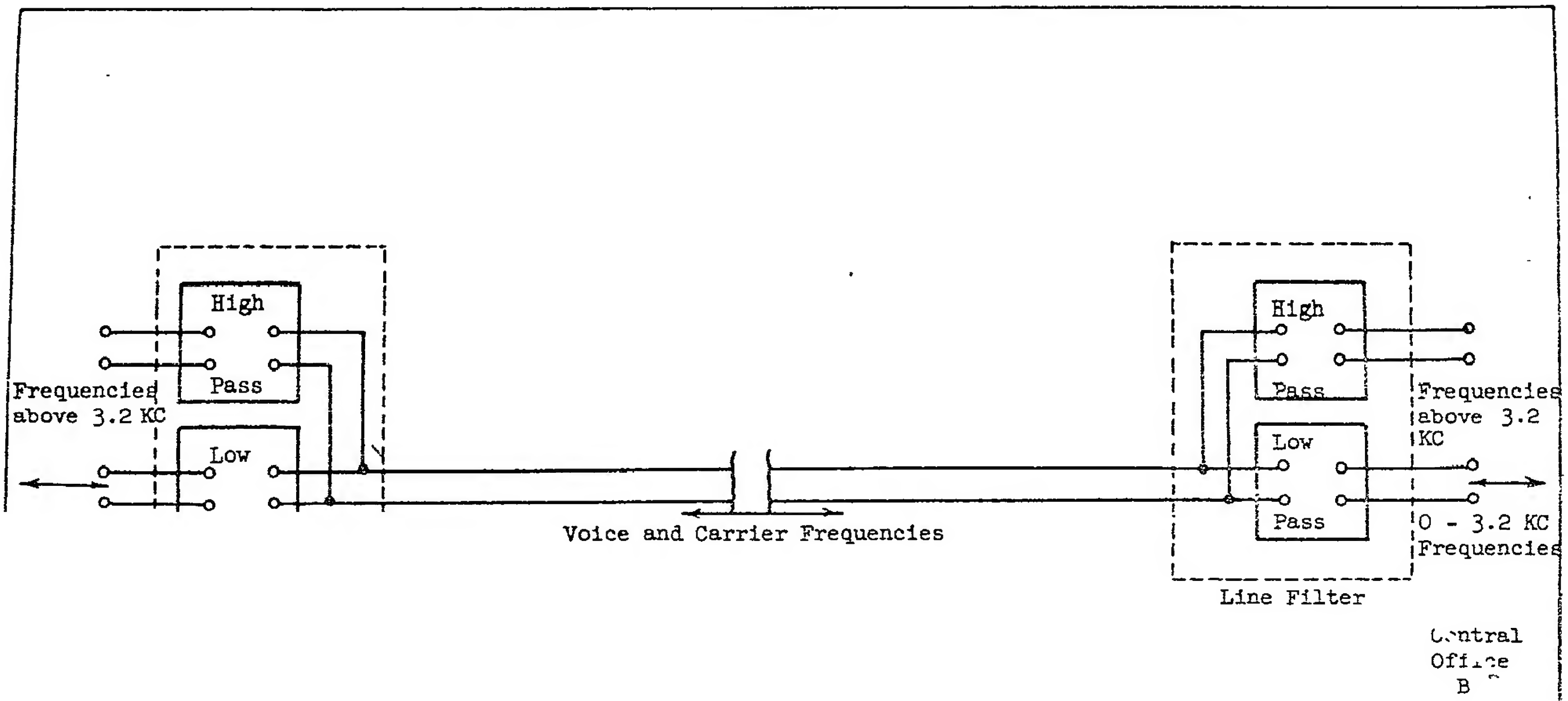
15.064 Differences in level along a carrier route with like systems on two or more wire pairs result in reduced crosstalk loss for the transposition system utilized. The magnitude of the reduction in crosstalk loss that occurs is a function of the amount of level difference and the length of the circuit (degree of exposure) over which the level difference exists. In order to reduce the possibility of crosstalk for the example given in Fig. 8 the transmit output power of the carrier terminal at location C would [illegible] reduced. The new transmit po[illegible] which would give a suitabl[illegible] the crosstalk loss under th[illegible] conditions for which coordi[illegible] In this example the transmi[illegible] location C would be reduce[illegible] would result in a new trans[illegible] Under this arrangement ther[illegible]

of approximately 0.1 to 0.2 db in received levels when the attenuation at carrier frequencies varies due to wet or dry weather conditions.

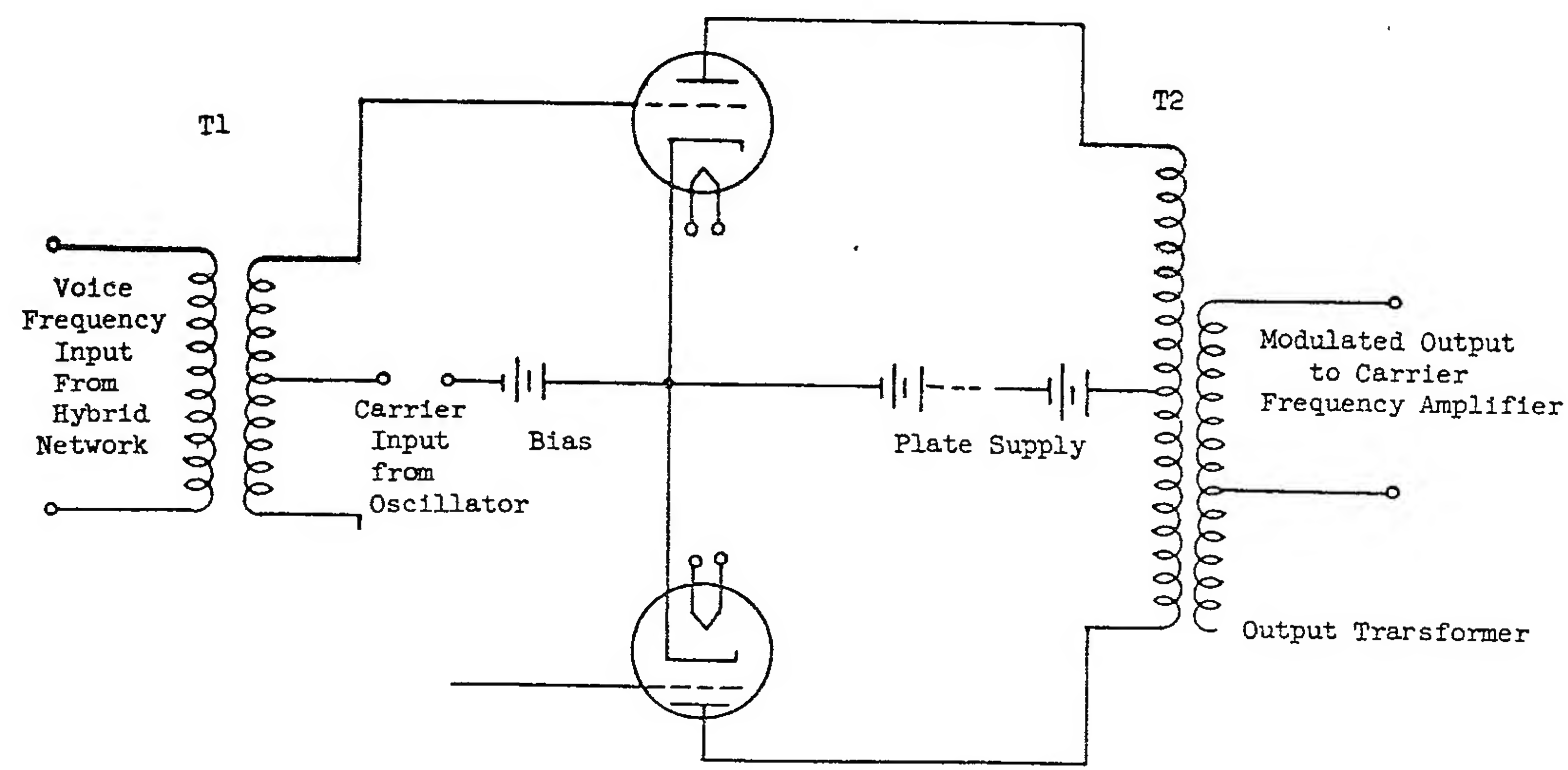
15.065 Other possible methods for increasing the crosstalk loss in situations where level differences occur, provided that the crosstalk loss is not sufficiently high to begin with, would be by the use of compandored equipment (Par. 10) or by the installation of carrier repeaters at locations such as X for the A-B carrier shown in Fig. 8. The use of repeaters in level coordination situations should only be considered in carrier application situations when all other means of providing such coordination are not technically feasible.

15.066 The maximum effectiveness of any transposition system in minimizing intelligible crosstalk can only be realized when coordinated levels are provided in situations where like carrier systems are superimposed upon various open wire pairs along a route.

Similarly, coordination of levels should also be provided for carrier systems employing frequency staggering arrangements in similar situations in order to minimize unintelligible crosstalk.

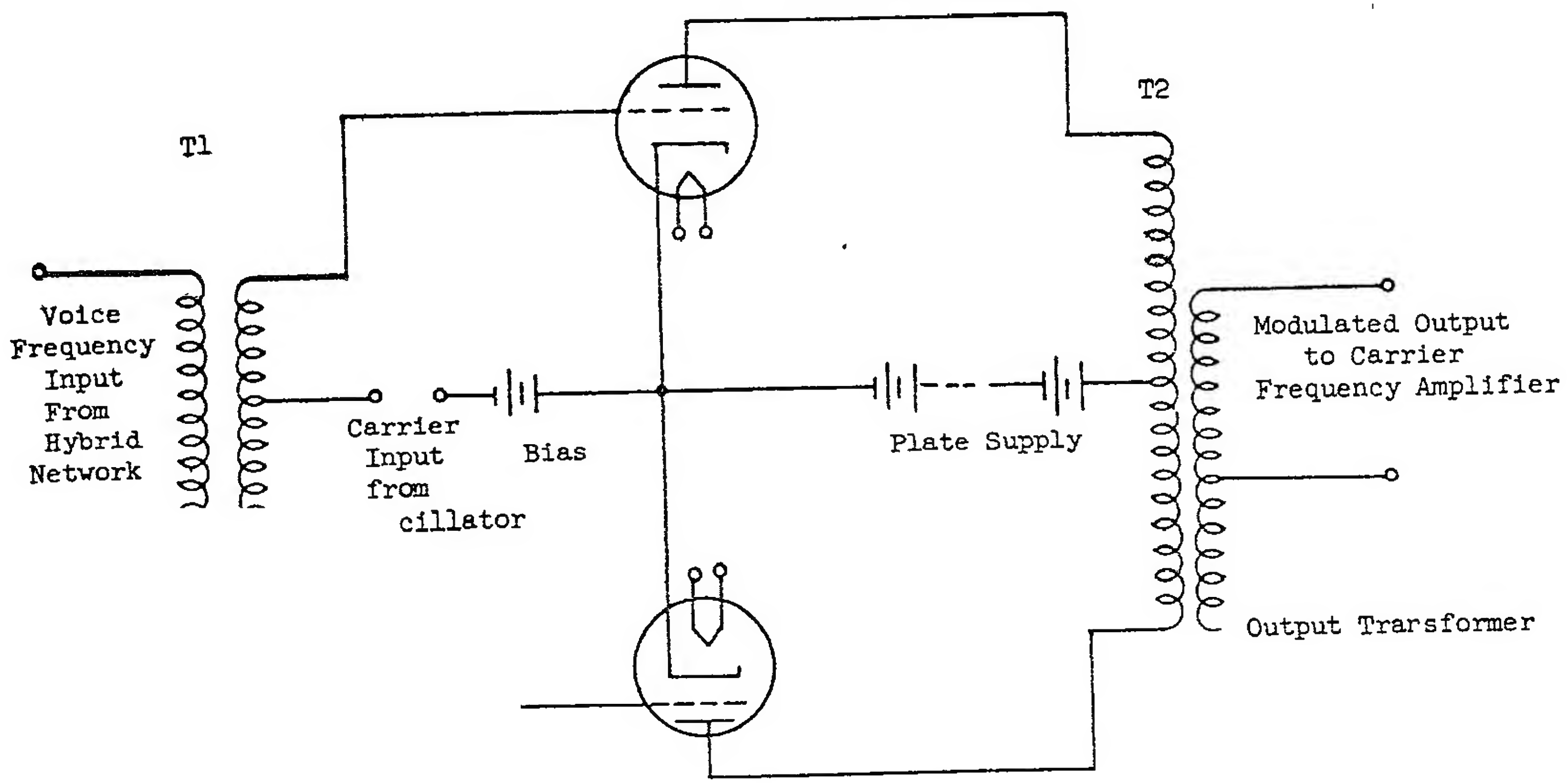


LINE FILTER APPLICATION

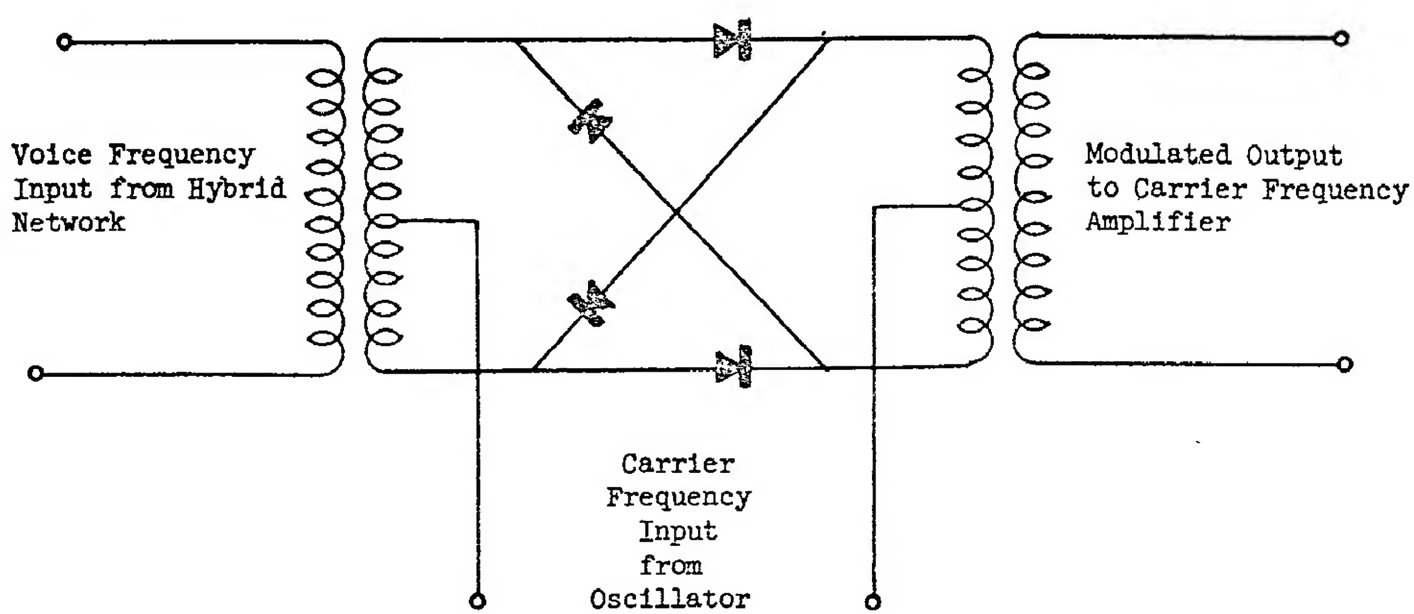


ALANCED MODULATOR EMPLOYING VACUUM TUBES

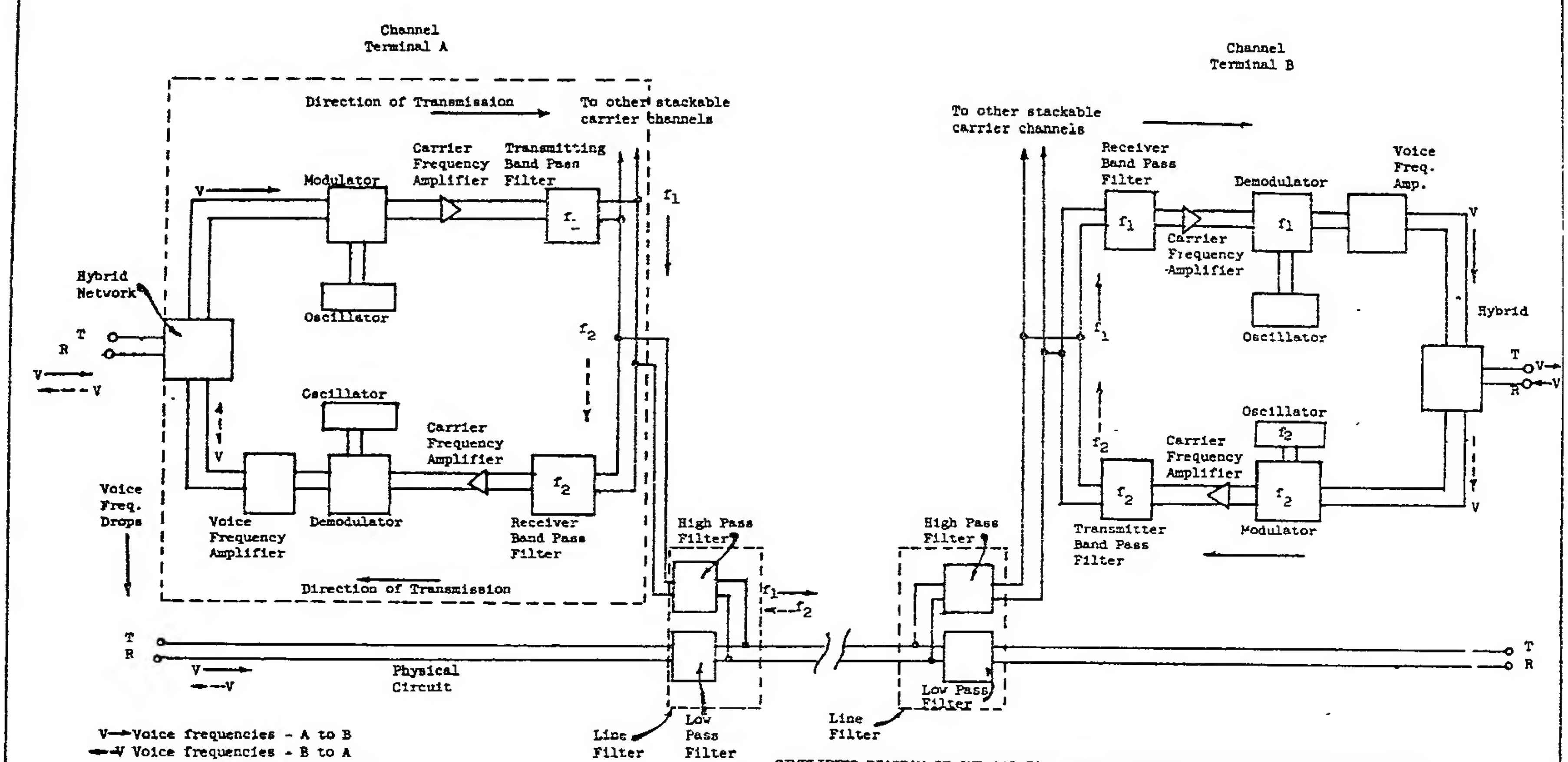
FIGURE 2



.ANCED MODULATOR EMPLOYING VACUUM TUBES



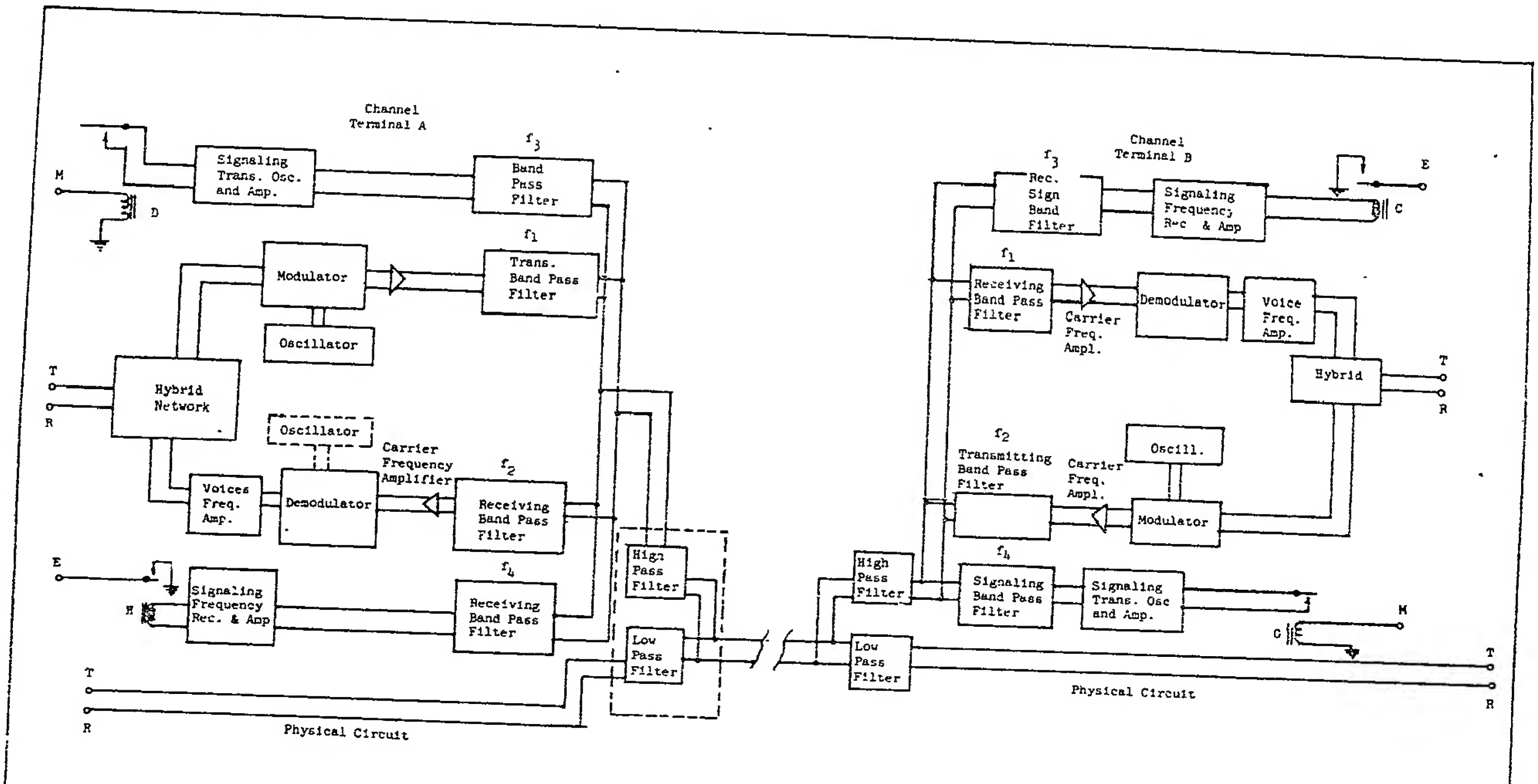
BALANCED MODULATOR EMPLOYING DIODES



SIMPLIFIED DIAGRAM OF ONE CARRIER CHANNEL SUPERIMPOSED UPON A PHYSICAL CIRCUIT

NO SIGNALING PROVISIONS SHOWN

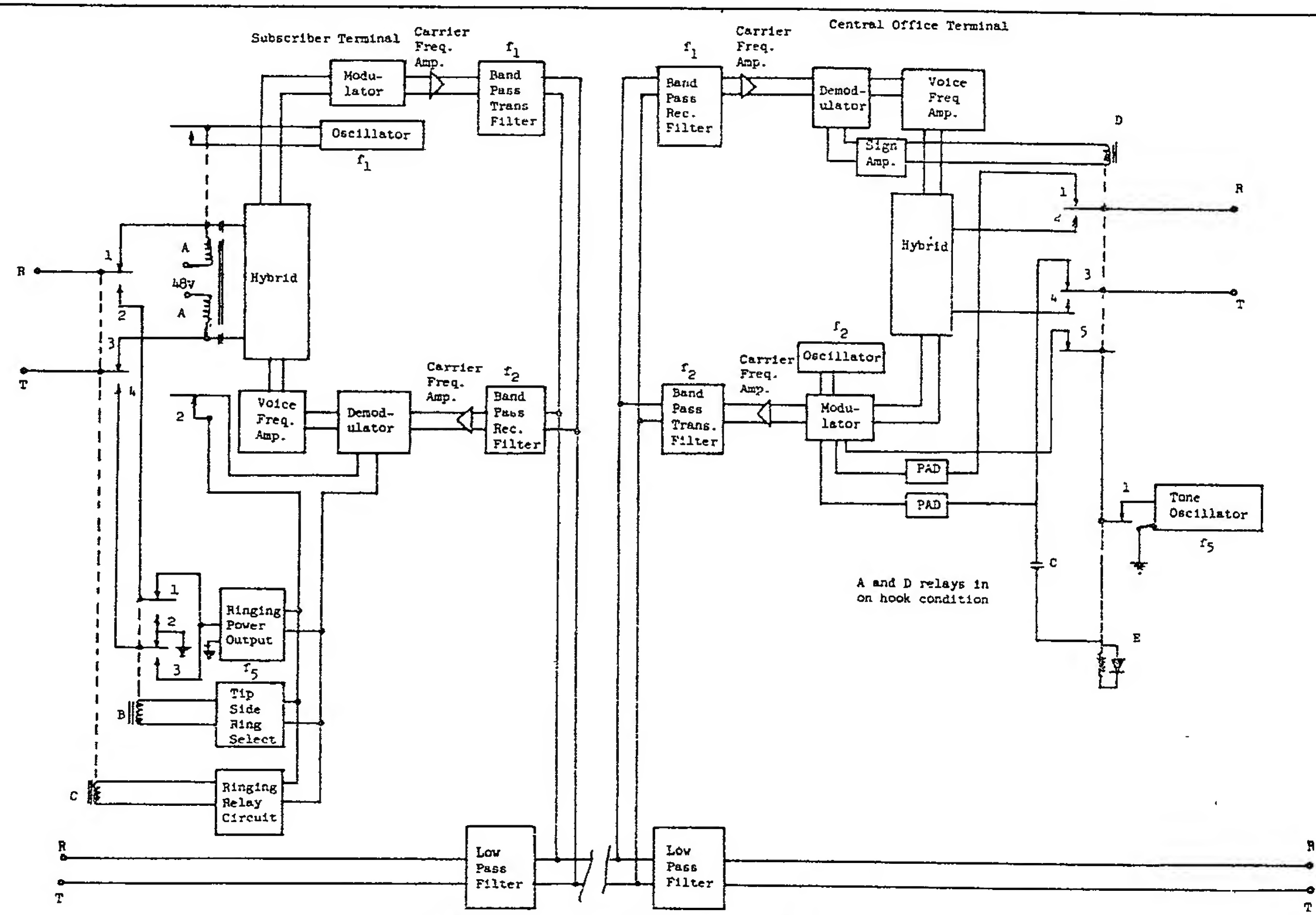
FIGURE 5



SIMPLIFIED DIAGRAM TRUNK CARRIER CHANNEL E & M LEAD SIGNALING

BY-OUT-OF BAND FREQUENCIES

FIGURE 6



SUBSCRIBER CARRIER CHANNEL FULL SELECTIVE RINGING

SIMPLIFIED DIAGRAM

FIGURE 7

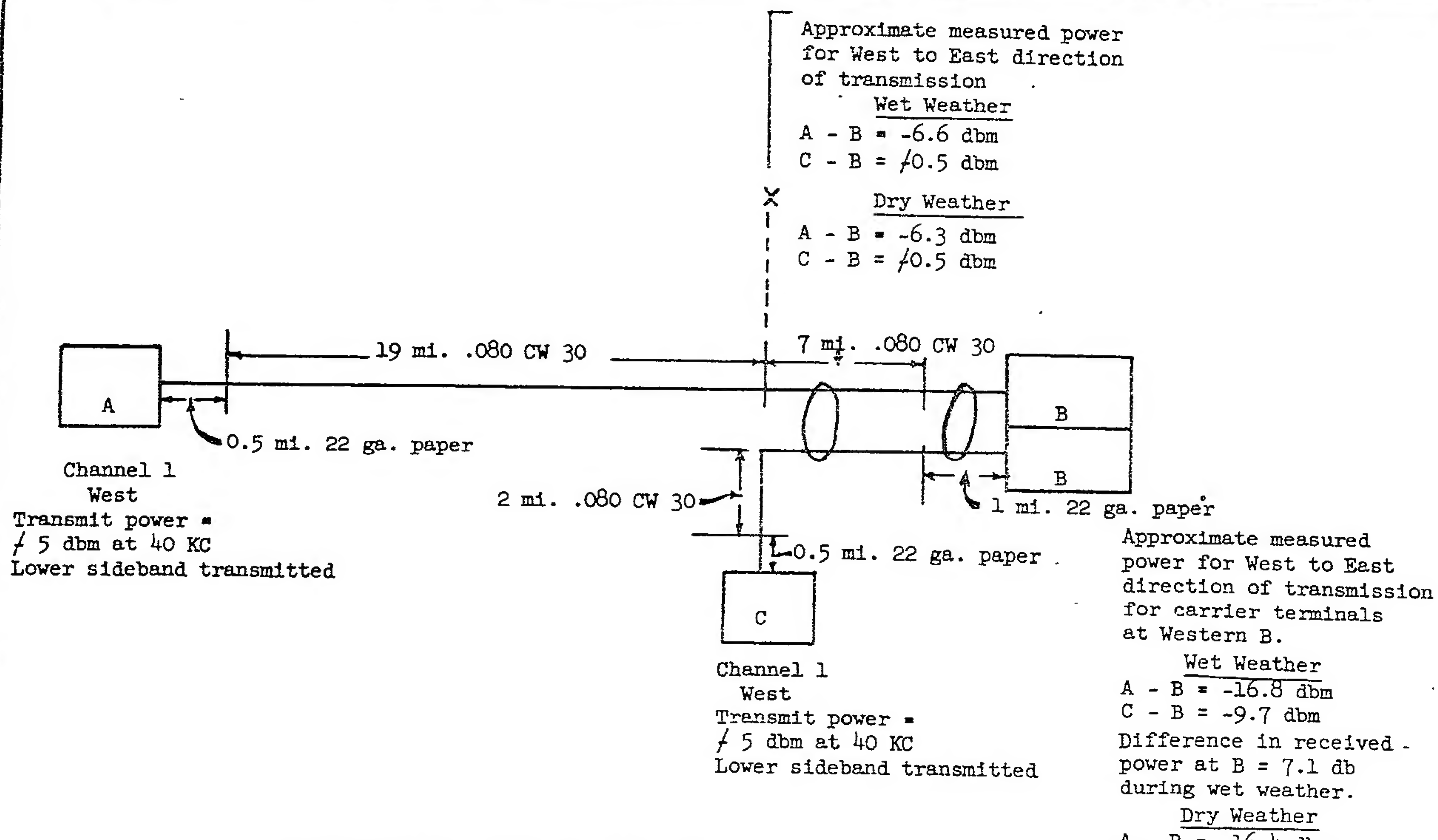
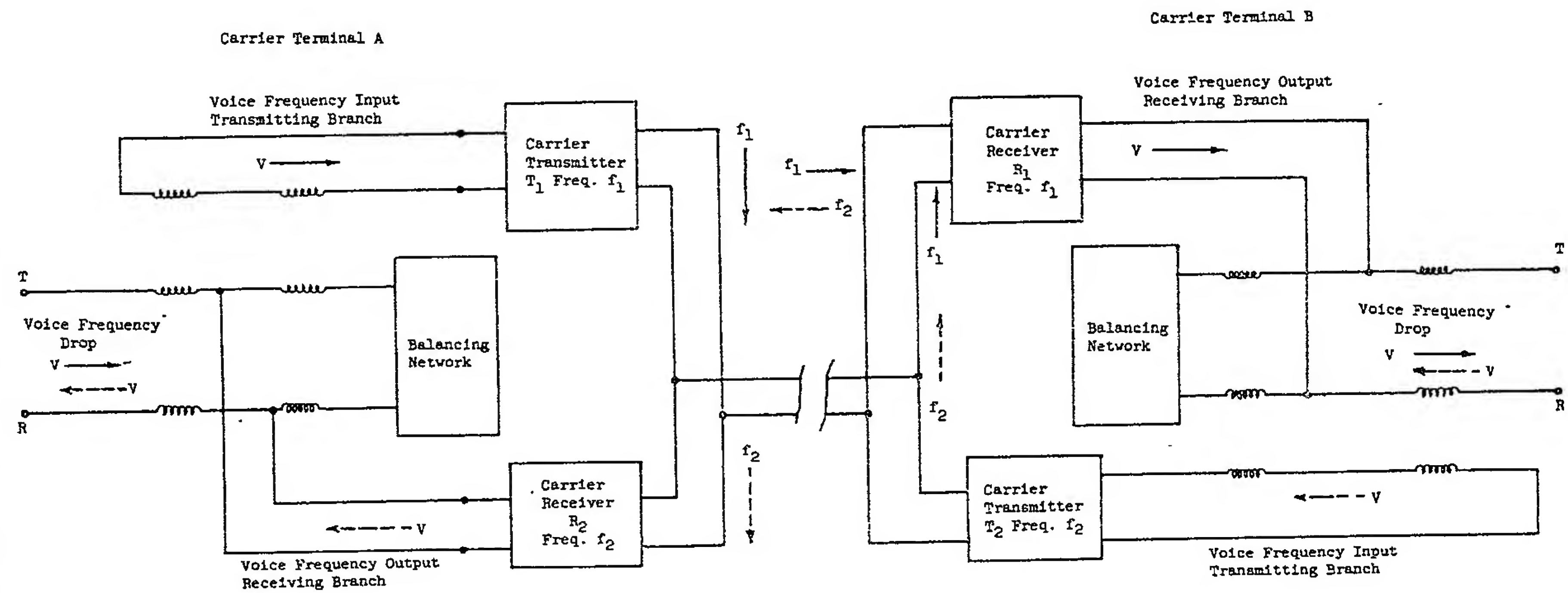


ILLUSTRATION OF RECEIVED POWER DIFFERENCES FOR CARRIER TERMINALS AT LOCATION B BEFORE LEVEL COORDINATION

FIGURE 8 .



V ⟶ Voice frequencies A to B direction

⇠ V Voice frequencies B to A direction

f_1 ⟶ Carrier frequencies A to B direction

⇠ f_2 Carrier frequencies B to A direction

SIMPLIFIED DIAGRAM SHOWING HYBRID TERMINAL CONNECTIONS

FIGURE 4